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CLOUD FIELDS DERIVED FROM SATELLITE AND SURFACE DATA DURING FIRE CIRRUS PHASE II

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INTRODUCTION

The interpretation of surface and aircraft measurements of cloud properties taken during field programs must take into account the large-scale cloud and meteorological conditions. Cloud properties are also required at scales beyond the point and line data taken from ground and aircraft platforms. Satellite data can provide a quantitative description of these large-scale cloud properties. When derived from geostationary satellite data, the cloud fields constitute a unique source for evaluating the development and demise of a cloud system. Satellites, however, can only see the tops of clouds, so that cloud layers below the uppermost cloud deck may remain undetected resulting in a incomplete depiction of the cloud system. Some multilayer clouds are amenable to detection from satellites. Many, especially in midlatitude cyclonic systems, can only be observed from the surface. A combination of surface and satellite cloud observations should be the most complete quantification of large-scale cloudiness if there are sufficient surface measurements.

During the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment Phase II (FIRE-II) Cirrus Intensive Field Observation (IFO) period (November 13 - December 7, 1991) conducted at Coffeyville, Kansas, cirrus observations were taken in a variety of conditions. The IFO area was selected for a variety of reasons including the relatively dense network of surface weather stations and special surface instrumentation sites. Thus, the FIRE-II IFO presents an excellent opportunity to combine cloud observations from surface and satellite observations. This paper presents an analysis of cloud properties on a mesoscale grid using satellite cloud property retrievals, surface observer data, and rawinsonde temperature and humidity profiles.

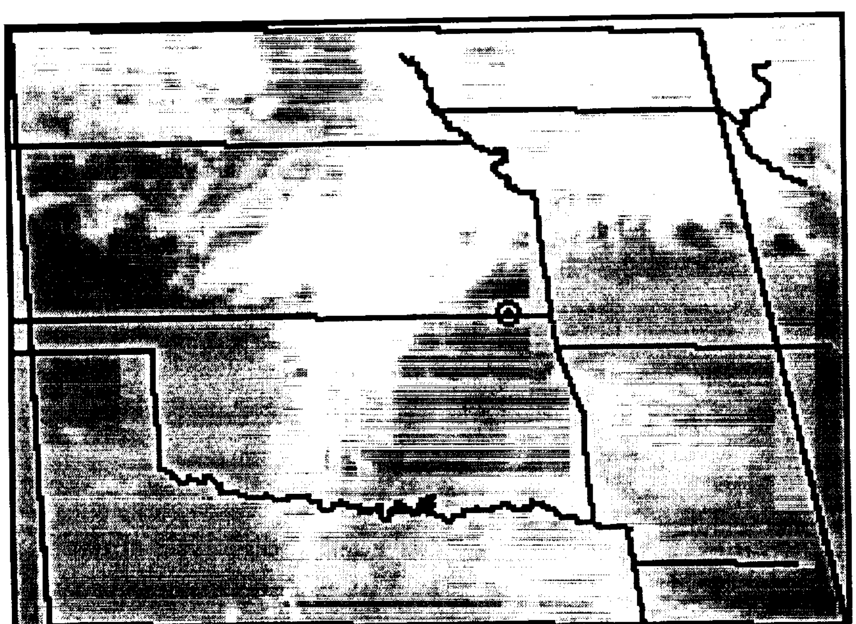

Fig. 1. GOES IR image from 1800 UTC, November 26, 1991.

DATA AND METHODOLOGY

Half-hourly, visible (0.65-μm, VIS) data from the Geostationary Operational Environmental Satellite (GOES-7) were averaged to a resolution of 8 km and matched with 8-km infrared (11.2 μm, IR) data to form two-dimensional histograms of pixel radiances for a 0.5° latitude-longitude grid bounded by 32°N and 42°N latitudes and 92°W and 102°W longitudes. The VIS-IR histograms were analyzed with the methodology of Minnis et al. (1993) to produce a three-level cloud dataset. At each level, low (below 2 km), middle (between 2 and 6 km), and high (above 6 km), the analysis produces cloud fractional coverage C_{si}, cloud-top height z_{si}, and cloud optical depth τ_i, where the subscripts s and i refer to satellite and cloud layer (low = 1), respectively. The total cloud amount C_s is the sum of the three layers, while the average cloud height and total optical depths are the cloud-amount weighted sums of the three layer values. Clear-sky temperatures used in the analysis are derived using the technique of Minnis et al. (1987) with some supplementary data provided from the surface observations. National Meteorological Center (NMC) gridded meteorological analyses were used to relate cloud IR temperature to cloud altitude. The VIS data were converted to reflectance using a calibration based on surface measurements at White Sands, New Mexico (Charles Whitlock, NASA Langley Research Center, personal communication).

Hourly surface observations were acquired from the University of Wisconsin Man-computer Data Analysis System (McIDAS) for 43 stations within the domain. The observations include cloud base height (in feet above ground) and nominal coverage (scattered, broken, or overcast) for up to 3 levels. Surface temperature was also recorded for each station. Six-hourly rawinsonde data were available for selected stations. Scattered, broken, and, overcast were assigned cloud fractions of 33, 67, and 100%, respectively, for each level. The clouds were assigned to the low, middle, and high layers by the recorded cloud-base height. If two surface-observed cloud layers were located in the same height layer, the sum of the two amounts were assigned to that height category. The resulting layer cloud amounts for a given station were assigned to the 0.5° region in which the station was located. If two or more stations were in the same region, averages of the station values were assigned to each height category for that region. Total surface cloudiness C_g is the sum of the individual layer cloud amounts unless that sum is greater than or equal to 100%. In that case, $C_g = 100\%$.

Because of reporting methods, some stations recorded clear skies and missing values in the same manner preventing a unambiguous determination of clear sky stations. For that reason and because of the sparse spatial sampling by the surface observers, the surface observations were prepared in the following manner before combination with the satellite data. Regions deemed clear ($C_s < 1\%$) by the satellite analysis were added to the surface regional dataset. A Gaussian interpolation scheme was then applied to the combined clear satellite-cloudy surface regional dataset to estimate a cloud amount value at each height category for every region. The final cloud amount value for each region was determined using the following logic.

For high clouds: If $C_{s3} > 0$, then $C_3 = C_{s3}$.
Otherwise, $C_3 = C_{g3}$.

For low clouds: If $C_{s2} + C_{s3} = 100$, $C_1 = C_{g1}$.
If $|C_{s1} - C_{g1}| > 15$, C_1 = greater of C_{g1} and C_{s1}.
If $|C_{s1} - C_{g1}| < 15$ and $C_{g1} < 100$, $C_1 = C_{s1}$.

For midlevel clouds: If $C_{s3} = 100$ and $C_{g1} = 100$, C_2 = undefined.
If $C_{s3} = 100$ and $C_{g1} < 100$, $C_2 = C_{g2}$.
If $C_{s3} < 100$ and $C_{g1} = 100$, $C_2 = C_{s2}$.
If $C_{s3} < 100$ and $C_{g1} < 100$, $C_2 = C_{s2}$ if $|C_{s2} - C_{g2}| < 15\%$ or $C_{s2} > C_{g2}$, otherwise $C_2 = C_{g2}$.

All undefined values are filled by interpolation.

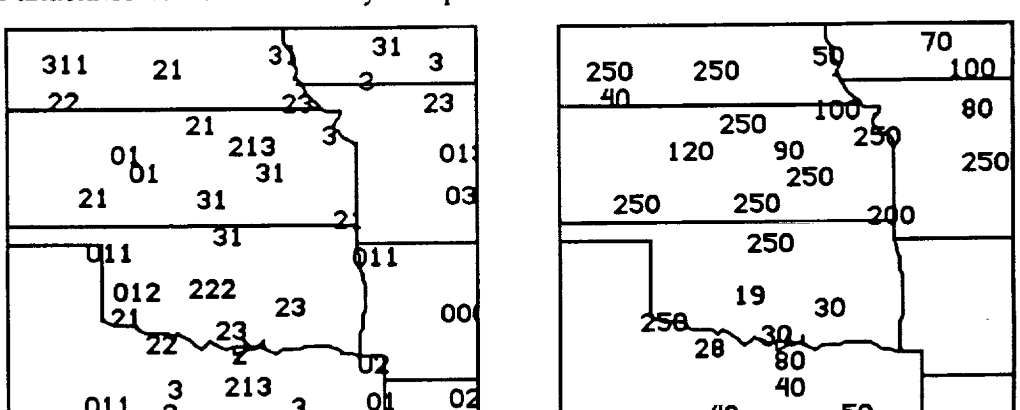

Fig. 2. Cloud data from surface reports, 1800 UTC, November 26, 1991. First panel indicates ceiling, first non-ceiling, and second non-ceiling (0=clear, 1 = scattered, 2 = broken, 3= overcast). Second panel indicates height in x 100 ft.

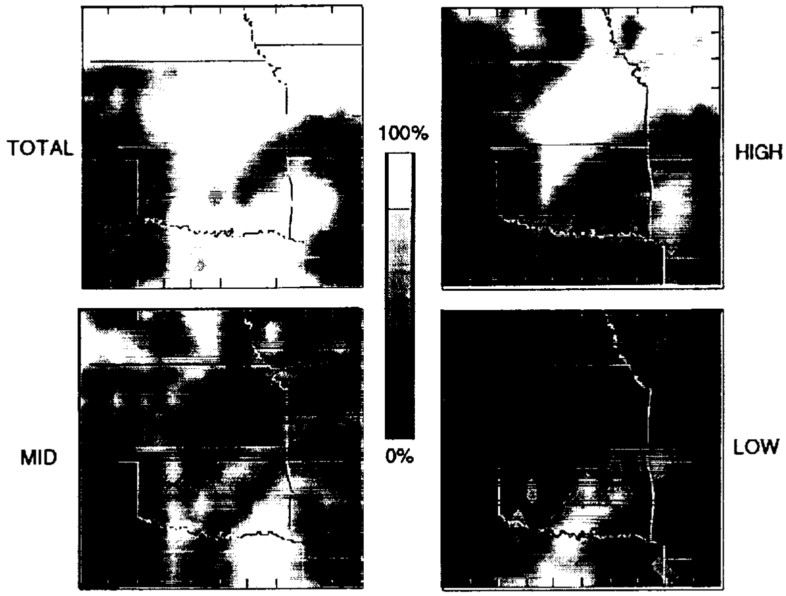

Fig. 3. Cloud Fraction derived from GOES data at 1800 UTC on November 26, 1991. The black areas indicate cloud fractions less than 1%.

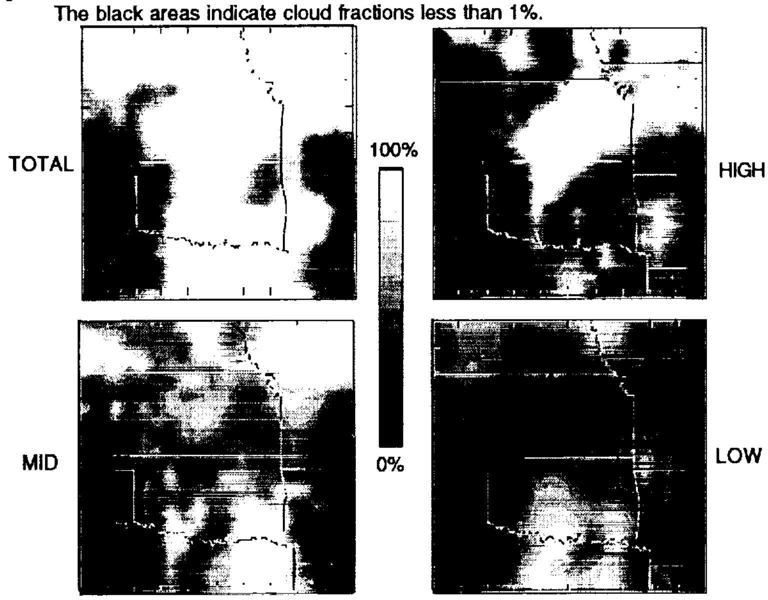

Fig. 4. Combined Satellite and surface derived cloud fraction for November 26, 1991 at 1800 UTC The black areas denote cloud fractions less than 1%.

RESULTS

Figure 1 shows the GOES IR imagery for 1800 UTC, November 26, 1991. Examples of the surface-observed cloud conditions in Fig. 2 indicate overcast conditions over much of Nebraska, Iowa, central and eastern Kansas, and central Texas and Oklahoma. The lowest cloud ceilings observed from the surface (Fig. 2b) vary from 2000 ft to 25,000 ft (the maximum reported value is 25,000 ft regardless of true height). Low clouds are the lowest clouds seen over northern Texas, central Oklahoma, and southern Nebraska and Iowa. Midlevel clouds are the lowest observed decks over much of Kansas, while high clouds are the only clouds reported over central Arkansas, the Texas panhandle, and the area just north of Coffeyville, Kansas. A somewhat similar picture is seen in the satellite analyses (Fig. 3) with some notable exceptions. No low clouds were detected over Nebraska and Iowa. Midlevel clouds were found over northeastern Texas. High clouds are the only type retrieved over most of eastern Kansas, Iowa, and northern Missouri. Combining the two datasets yields the contours in Fig. 4 that show midlevel clouds extending as far south as central Missouri and covering much of Kansas. Low clouds are also found over much of Nebraska and Iowa.

DISCUSSION

These results have important ramifications for using satellite data to verify cloud-process model results and to determine the radiative properties of clouds. The western and northern portions of the large area of satellite-derived high cloudiness (Fig. 3) where midlevel clouds were observed from the surface (Fig. 2) have very high optical depths (Fig. 5). The optical depths for the high-cloud-only regions are all less than 4. Thus, it appears that the larger high-cloud optical depths are caused by thick cloud layers underneath the highest layer. The satellite misinterprets this as a very thick high cloud. For example, the sounding over Omaha (Fig. 6) indicates thin clouds with tops at ~250 and 420 mb over a very thick cloud with a top near 510 mb. A low deck is apparent at ~ 910 mb. The average satellite-derived cloud height over Omaha is 350 mb. The optical depth is assigned to the high cloud since that is the only cloud type seen over Omaha from the satellite. Most of the optical depth belongs in the midlevel clouds. Using the combined dataset (Fig. 4), we can estimate cloud cover over Omaha as being overcast high clouds, 50% midlevel, and 80% low. While the sounding suggests that this result is not complete, it is much closer than the satellite alone. To improve the analysis further, it is necessary to use the available soundings and cloud thickness-optical-depth relationships (e.g., Smith et al., 1993) to flesh out the middle levels and to estimate the optical depths for clouds not seen by the satellites. Such an approach is probably feasible only over areas of dense surface networks.

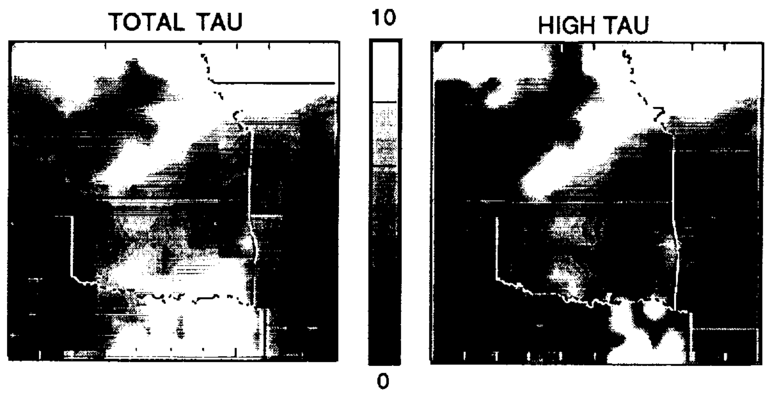

Fig. 5. Total and high cloud optical depths derived from GOES data at 1800 UTC on November 26, 1991. The black areas denote cloud fractions less than 1%.

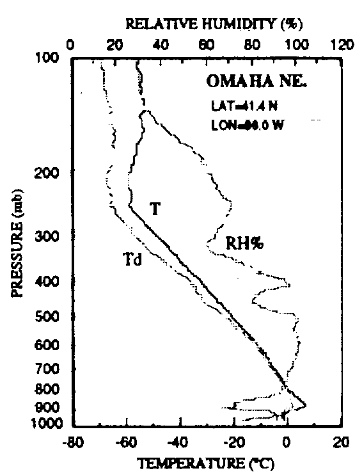

FIG. 6. Rawinsonde temperature and moisture profiles for Omaha, Nebraska at 1800 UTC on November 26, 1991.

CONCLUDING REMARKS

This paper has presented a preliminary combined surface-satellite cloud analysis for the FIRE-II region. Because cirrus clouds occur over lower clouds during much of the experiment and at any given time, it is important to account for the underlying clouds that cannot be detected from the satellite. The use of statistical relationships between cloud thickness and derived optical depth and other techniques such textural methods may improve the detection of multilevel clouds. When the higher clouds become optically black, however, there is little information to be derived from the satellite about the lower levels. For now, the only source for the lower-level information is in the surface or sounding data. The blending of surface and satellite data is a challenge requiring much additional research.

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